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Impact of problem solving on trigonometric learning in Afro-Colombian communities

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The article advocates for the need to adapt trigonometry teaching to Afro-Colombian communities through appropriate strategies that reflect their environment and culture, arguing that the use of authentic problem-solving is a relevant didactic design to foster meaningful learning, promote motivation, and strengthen students' identity. It is a qualitative, theoretical-conceptual study framed within the socio-critical paradigm and guided by the principles of Participatory Action Research (PAR). Although no fieldwork was conducted, a critical review of pedagogical, academic, and policy-related literature was carried out to support the design of a relevant educational proposal. The theoretical framework is built upon contextualized problem-solving, critical mathematics education, ethnomathematics, and PAR. It argues that teaching trigonometry through real-life problems enhances conceptual understanding, critical thinking, and the application of mathematical knowledge to everyday situations. Moreover, it highlights the potential for integrating ancestral knowledge related to navigation, topography, or Afro-Colombian craftsmanship. The results reveal both pedagogical and social advantages, as well as tensions and challenges such as misalignment with the official curriculum, gaps in teacher training, and limited resources. Nonetheless, the study also identifies opportunities to enrich teaching with culturally meaningful content. Finally, it proposes organizing participatory projects that connect teachers, students, and the community in the development of contextualized didactic materials, aiming for a more equitable, critical, and transformative mathematics education.

KEYWORDS

contextualized trigonometry, ethnomathematics, problem solving, experiential learning, critical mathematics education

1 Introduction

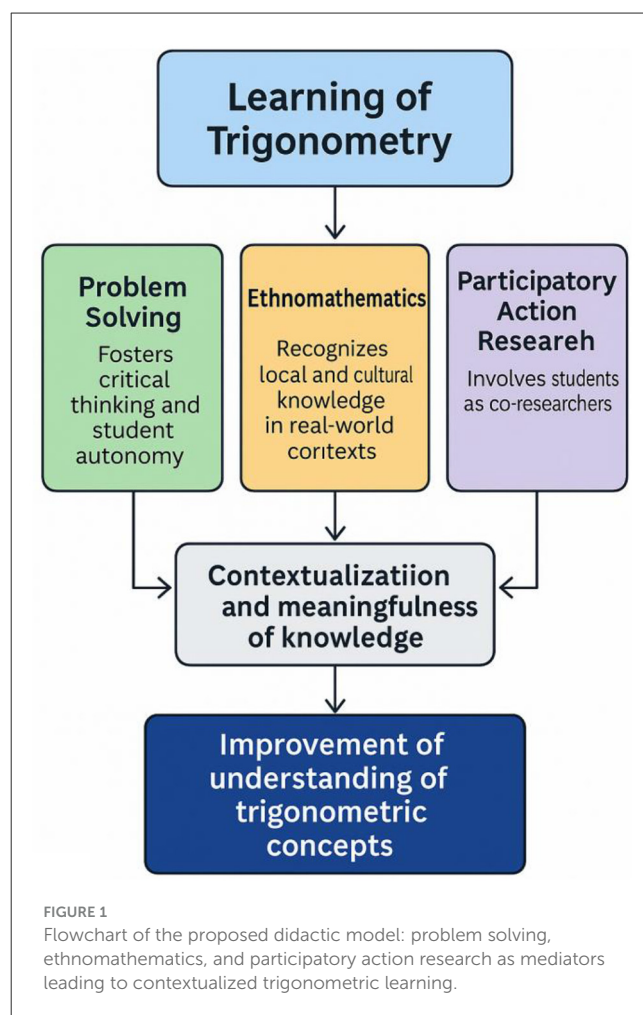
Afro-Colombian communities, with their rich cultural heritage and unique social contexts, have historically been subjected to educational inequalities reflected in unequal access to quality education and disparities in academic performance (Mora et al., 2021). Within the field of mathematics education, numerous international studies have demonstrated that race and ethnic origin can influence the contexts in which students experience learning. In fact, the learning of mathematics in school is often seen as a process of “racialization,” in which hierarchies of mathematical ability are constructed based on ethno-racial identity (Carriazo-Regino et al., 2024).

A clear example of this is the consistent observation that students from minority backgrounds tend to perform, on average, worse on standardized mathematics tests (Sánchez et al., 2023). This reality highlights the need to rethink didactic practices to ensure they are inclusive, contextualized, and culturally relevant particularly in Afro-descendant communities, where traditional schooling has often disregarded local knowledge and lived experiences (Carrillo et al., 2022).

In Colombia, the official curriculum recognizes the importance of contextualizing mathematical learning. The Basic Competency Standards in Mathematics issued by the Ministry of National Education define mathematical thinking as a set of skills that enables students to “formulate, pose, transform, and solve problems based on everyday situations,” in addition to modeling phenomena and engaging in mathematical communication and reasoning (Barreto and Avella, 2020). Trigonometry occupies a prominent place in the upper-secondary curriculum (10th grade) as a fundamental component of school mathematics (Mosquera, 2021). However, its instruction has traditionally been limited to the study of basic concepts or the resolution of specific problems. Despite curricular intentions, trigonometry is often taught from an abstract perspective disconnected from students’ realities, which can hinder meaningful comprehension (Contreras et al., 2021).

In Afro-Colombian communities where daily life, geography, and culture exhibit characteristics it is essential to implement contextualized didactic strategies that link trigonometry to students lived experiences (Tajuddin et al., 2023). In this regard, solving real-life problems becomes a highly meaningful pedagogical strategy (Maghfiroh et al., 2024). Incorporating authentic problems drawn from everyday life, cultural context, or the productive environment of students can give purpose to trigonometric concepts that would otherwise be explained solely in abstract or theoretical terms (Ngu and Phan, 2023). Moreover, the need for a contextualized and socio-critical approach extends beyond cognitive learning; it involves empowering students to become critical thinkers engaged with their community (Martínez-Padrón, 2021).

Therefore, this article adopts a qualitative and socio-critical perspective to establish a theoretical framework, based on relevant literature, that demonstrates how contextualized problem-solving can enhance trigonometric learning among secondary students in Afro-Colombian communities (Cuásquer-Viveros and Moreno-Cortés, 2021). It discusses the theoretical foundations and background of problem-based trigonometry instruction, the contributions of socio-critical and ethnocultural approaches in mathematics education, and the relevance of Participatory Action Research (PAR) as a didactic engineering methodology for connecting theory and educational practice in specific contexts (Amedume et al., 2022). The integration of contextualized strategies in trigonometry instruction is considered here not merely a pedagogical innovation but a social imperative to transform mathematics into an inclusive and meaningful tool for the education of Afro-Colombian youth (Gyan et al., 2021) (Figure 1).



2 Theoretical framework

2.1 Teaching trigonometry with a problem-solving approach

Trigonometry is a branch of mathematics that historically emerged to meet the practical needs of people involved in measuring distances and angles in basic situations (such as land surveying, navigation, or astronomy) (Nilimaa, 2023). However, in current educational practices, trigonometry is often taught in a formalist manner, detached from the everyday applications that originally justified its development (Arhin and Hokor, 2021). Didactic research has increasingly pointed out that “what would improve conceptual understanding and the ability to solve contextualized problems in trigonometry” is closely tied to concepts rooted in real-life situations. Fererde et al. (2024) explain that instruction based on real-world problem solving made “trigonometry lessons significantly more meaningful and relevant to students’ lives,” effectively connecting formal academic content to lived experiences (Takahashi, 2021).

In their quasi-experimental study, the group of students who learned trigonometry through authentic contexts outperformed

the control group, which learned it through general, traditional methods (Nanmumpuni and Retnawati, 2021). The findings indicated that solving problems based on authentic contexts in the classroom (e.g., calculating the height of a tree that cannot be directly measured using trigonometric ratios, or determining distances in their neighborhood by measuring angles) can trigger the learning of trigonometry. When faced with a real problem, students activate their prior knowledge, recognize the usefulness of trigonometric ratios, and are better able to transition from empirical understanding to abstract reasoning (Kirby et al., 2023).

Classroom experiences in Colombia have confirmed the effectiveness of this approach: 10th-grade students who connected trigonometric concepts to the measurement of real dimensions within their school reported that the activities were more engaging, and they better understood the mathematical concepts (de la Rosa, 2023). The activities designed by educators allowed students to recreate real-world measurement processes, using trigonometric ratios as concrete tools to answer meaningful questions (e.g., “What is the height of the school buildings?”) (Universidad Católica de del Maule Chile et al., 2021). This approach encouraged students to study sine, cosine, and tangent through the lens of authentic problem solving, where questions were derived from their own classroom experiences (Amalia et al., 2024).

Literature supports the view that teaching trigonometry through real-life problem solving not only enhances students’ mathematical competencies (measurement, modeling, and problem-solving), but also increases their motivation and self-confidence by demonstrating that mathematics is directly connected to their immediate environment (Fox and DeJarnette, 2022; Lozano et al., 2012).

2.2 Socio-critical approaches in mathematics education

From a socio-critical perspective, education including mathematics education is conceived as a tool for emancipation and social transformation. In contrast to traditional views that regard mathematics as neutral and ahistorical knowledge, socio-critical mathematics education recognizes that learning mathematics is deeply intertwined with issues of culture, power, and equity (Olawale et al., 2021). Scholars such as Ole Skovsmose and Paola Valero have argued that the teaching of mathematics must empower students to critique reality and act upon it, rather than merely adapting to given knowledge (Torres-Duarte, 2022). In Colombia, Critical Mathematics Education aligns with this socio-political dimension, as it is based on the consideration of all human beings as political subjects; more specifically, that students can exercise power from within the mathematics classroom (Puentes et al., 2022).

This means that the mathematics classroom can and should become a space for developing critical thinking, discussing community issues through mathematical resources, and raising awareness about how mathematical knowledge can be connected to social realities (Castiblanco, 2022). For example, students may analyze inequality within their neighborhoods or model

scenarios that reflect social justice using mathematical tools (Giraldo et al., 2022). Critical theory, inspired by the Frankfurt School, frames the socio-critical paradigm as one aimed at forging social transformation through the pursuit of solutions to individual problems involving the active participation of community members (Fresneda-Patiño and Coral, 2023). In this context, mathematics education seeks to instill in students an active and reflective role, emphasizing that mathematical knowledge can be applied to understand and improve their own realities thus breaking away from the presumed neutrality of mathematical content (Olawale et al., 2021).

Ultimately, a socio-critical conception of the discipline aims to dismantle the “ideologies of neutrality” and provide students with conceptual tools to make mathematics a means of social critique (Janzen, 2022). This is especially relevant in Afro-Colombian communities: such an approach allows students to make visible and question issues of inequality such as limited access to educational or technological opportunities and repositions Afro-descendant students as capable of producing valuable mathematical knowledge. It also challenges deeply rooted racial stereotypes that have historically cast them as “incapable” of engaging in such practices (Andersson and Barwell, 2021; Garcia, 2021).

The paradigmatic model of research is the socio-critical paradigm, which focuses specifically on analyzing social, economic, and political structures to understand and transform reality. This paradigm is the one most directly related to critical pedagogy, where knowledge is conceived as a lever for social emancipation and the fight against injustice. The different research approaches within the paradigm investigate reality in order to transform it, but without neglecting praxis, critical reflection, and social action (Freire, 1970; Giroux, 2001).

This paradigm corresponds to a qualitative approach and a Participatory Action Research (PAR) method for interpreting the pedagogical experiences of teachers in Afro-descendant ethno-educational institutions. It allows for exploring how teachers construct and implement these experiences within the sociocultural context in which they are embedded (Reale and Antiseri, 1993).

The research focuses on identifying and analyzing teachers’ perceptions and pedagogical practices to propose a critical approach based on problem-solving. In this way, the didactic proposal not only seeks to improve the teaching of trigonometry but also promotes the development of a more equitable and liberating education that recognizes and values the cultural specificities of Afro-descendant communities (Carrillo et al., 2009).

The type of research applied in this study is qualitative and is guided by the Participatory Action Research (PAR) method, which allows for a thorough and in-depth investigation of the experiences of teachers at Afro-descendant ethno-educational institutions regarding the teaching and learning of trigonometry. Qualitative research is particularly relevant to understanding the complexity of teaching strategies, allowing for a detailed analysis of the impact of these influences on educational processes (Carrillo et al., 2009). Through semi-structured interviews, observations, and document analysis, we seek to capture the essence of the participants’ pedagogical practices and subjective interpretations. This methodology allows for the collection of rich and meaningful data in context and, in turn, the construction of a critical

didactic approach that addresses the specific nature of the type of educational space being studied.

In addition, regarding the contributions found in Carrillo et al. (2009) and other authors, the following phases are proposed for implementation in this research.

2.2.1 Phase 1: participatory diagnosis

In this first phase, the objective is to conduct a participatory diagnosis involving teachers, students, and the educational community to determine the problems and needs affecting the teaching of trigonometry. This must be done in a participatory manner; that is, the subjects involved must carry out the data collection and analysis. Kemmis and McTaggart (2019, p. 174): “Participatory diagnosis helps to identify problems more richly and contextually because the interview with educational stakeholders precipitates the reflection-action process.”

2.2.2 Phase 2: planning and designing teaching strategies

Based on the diagnosis, teaching strategies can be planned based on the identified needs. This design must include both a critical approach and a culturally relevant approach, taking into account the aspects of African-descendant students and their social context. The goal is to develop classroom activities that use trigonometry to reflect on the social and cultural environment. Cochran-Smith et al. (2016, p. 21): “Planning means doing so flexibly, leaving room for pedagogical approaches that reflect and connect with what is social and cultural.”

2.2.3 Phase 3: implementation and pedagogical action

In this phase, the strategies designed in the previous phase are implemented in the classroom. Here, teachers implement new teaching methodologies based on problem-solving and a critical perspective, while creating a space for ongoing dialogue and reflection in front of students. They want to teach trigonometry, but they also want to involve students in the way learning takes place and offer constructive criticism of their education. “PAR pedagogical action must be distributed in a participatory and dynamic manner, with students taking the lead in learning and maintaining critical reflection on the context.”

2.2.4 Phase 4: reflection, evaluation, and feedback

The final phase is a reflective evaluation of the strategies implemented in response to the results obtained. This phase not only focuses on student evaluation but also emphasizes a critical re-evaluation of teachers’ pedagogical practices. Teachers and students must jointly reflect on what has worked and what has not worked, and consequently, adjust strategies to improve the teaching-learning process in the future Nussbaum (2018, p. 132): “the evaluation of the PAR is a continuous and reflective process that involves mutual feedback between teachers and students to improve educational practices and ensure that the transformation objectives are achieved.”

2.3 Education in Afro-Colombian communities and ethnomathematics

Educational initiatives aimed at Afro-Colombian populations have, over recent decades, fostered a range of concrete pedagogical proposals under the umbrella of ethnoeducation, which refers to Colombia’s official educational policy directed toward ethnic groups. This form of education is defined as one that is delivered in ways that respect and strengthen the culture, language, traditions, and knowledge of these communities. Ethnoeducation emerged as a response to the “difficulties caused by decontextualized educational processes” that ethnic communities have historically endured. In the case of Black communities, there has been clear evidence of a profound disconnect between the school curriculum, its associated methodologies, and the students’ sociocultural context (Agudelo et al., 2024).

This disconnect has led many Afro-Colombian youth to perceive academic content, particularly mathematics as detached from their reality, resulting in poor academic performance and a lack of motivation. In this context, both academic and social movements have advocated for the integration of community knowledge and cultural practices into the formal curriculum (Quintero, 2022). The Afro-Colombian Studies Chair, which has been mandated by law since 1993 and regulated in 1998, seeks to include the history, contributions, and values of Afro-Colombian peoples across all levels of national education. Although the CEA was initially designed for the social sciences, there has also been a push for mathematics to be enriched by this perspective, thereby acknowledging the contributions of Africans and African diasporas to the development of mathematical knowledge.

Ethnomathematics, understood as the subdiscipline of mathematics education that explores the relationship between culture and mathematical thinking, forms part of this movement. Ethnomathematics seeks to highlight and value the counting methods, measurement systems, calculation techniques, and geometric concepts inherent to each culture, connecting them to the formal teaching of mathematics (Fresned-Patiño et al., 2023). In Afro-descendant communities, this could involve integrating traditional knowledge (such as coastal navigation techniques, rhythmic musical patterns, hair braiding, and local artisanal or architectural designs) to teach equivalent mathematical concepts (Aragón et al., 2024). Ethnomathematics and its relationship with ethnoeducation have posed not just a challenge but a pressing need for many educators, who often report difficulties in “relating mathematics to the students’ sociocultural context,” which has hindered the integration of ethnoeducation into mathematics instruction (Gavarrete and Albanese, 2022).

Authors such as Ashari and Alimuddin (2024) argue that “ethnomathematics has strong ties to the curriculum and seeks to permeate de facto curricula in basic, secondary, and ethnoeducation through the results of research into various cultures.” In other words, there is a call to develop didactic designs in which school mathematics concepts engage in dialogue with the lived contexts of Afro-Colombian students (Fouze and Amit, 2023). Several studies have delved into this process; for example, presents an experience in strengthening ethnomathematical education through the integration of fractal geometry concepts and images

inspired by Afro hair braiding as expressive cultural translations. This demonstrates the feasibility of incorporating advanced mathematical content through the traditional practices of the community (de Castro, 2024).

Although trigonometry has not yet been fully explored within the field of Afro-Colombian ethnomathematics, numerous potential entry points exist (such as using solar shadow measurements for orientation, thin roofing structures in local housing, and angular patterns in artisanal objects) that could be incorporated. In summary, the reviewed literature suggests that integrating mathematics education into Afro-Colombian contexts through ethnocultural approaches can not only enhance the relevance and understanding of content but also contribute to students' identity affirmation by validating community knowledge within the school environment (Rosa and Orey, 2021).

Afro-descendant communities in Colombia, although they share a common African origin, present cultural, historical, and territorial differences that are recognized and protected by national legislation. Law 70 of 1993, in its education chapter (arts. 39–44), recognizes that Black communities are not homogeneous but diverse in their cultural practices, knowledge systems, and forms of social organization, which requires differentiated ethno-education according to the regional and cultural context. Furthermore, Decree 1122 of 1998 emphasizes that educational proposals must respond to the particularities of each community, recognizing their languages, ancestral knowledge, and worldviews. The Afro-descendant communities covered in this study belong to the District of Cartagena de Indias, Department of Bolívar.

2.4 Participatory action research (PAR) in education

Participatory Action Research (PAR) is a qualitative social research methodology aimed at ensuring that members of a community actively participate in the research process, with the explicit goal of generating change within that community (Yáñez, 2022). This method, initially developed from the directives of Kurt Lewin in the 1940s, has been further enriched by Latin American theorists such as Orlando Fals Borda and Paulo Freire (Espinosa, 2022). PAR specifically seeks to eliminate the division between the researcher and the research subjects; in this framework, those who were traditionally considered the “object of study” become protagonists of the entire process. In this sense, teachers, students, and community members participate alongside the researcher from the identification of problems through data collection, analysis, action, and reflection on the results (Oliveira, 2023).

It is a form of research with the people, not on the people, in which knowledge is co-constructed between the researcher and the community (Gelabert et al., 2023). PAR does not merely aim to describe reality; rather, it functions to help groups of people develop their capabilities to identify problems and find their solutions to improve their reality (Sosnowski et al., 2022). In education, this means that PAR encourages teachers to become researchers of their practice and promotes the role of students and communities as active participants in educational transformation (Omodan and Dastile, 2023).

It is important to emphasize that PAR, by involving all actors in the educational process, democratizes the production of knowledge and highlights local knowledge systems (Varas-Contreras et al., 2023). Teachers contribute their pedagogical expertise to addressing the learning problem; students contribute their perspectives and lived experiences; and the broader educational community provides cultural traditions and local knowledge (Martínez and Negrete, 2024). Together, these contributions lead to a more comprehensive educational solution (Cornish et al., 2023).

For mathematics education in Afro-Colombian communities, PAR is considered one of the most suitable methodologies, as it allows curricular improvements such as the contextualization of trigonometry to be co-designed with the educational community (Rosenblatt, 2024). In this way, curricular adaptations respond to real needs and fulfill cultural requirements (Nicolás, 2021). In sum, PAR provides a framework in which theory is collaboratively transformed into practice, and most importantly it ensures that any didactic proposal, such as the one presented in this document, is developed with the sociocultural context in mind and with the prior commitment of those who are the direct protagonists of the educational process (Velásquez et al., 2021).

Although Colombia has regulations such as Law 70 of 1993 and Decree 1122 of 1998, the effective integration of the ethno-educational approach into the curriculum and teacher training is still limited. Teaching remains dominated by Eurocentric models, and many teachers are not trained to adequately address Afro-Colombian cultural diversity (Carriazo-Regino et al., 2024). Moving forward, it is necessary to include Afrocentric content in teacher training programs and allow greater community participation in curriculum development (Álvarez, 2020; Restrepo and Salgado, 2013).

3 Materials and methods

This study is framed within a qualitative research approach and is situated in the socio-critical paradigm of educational research. As a qualitative study, the aim is not to quantify effects or to statistically generalize the results (Martínez and Negrete, 2024). Instead, it seeks to delve deeply into and understand an educational phenomenon within a specific context. Choosing the socio-critical paradigm entails a desire to study the educational issue at hand (the learning of trigonometry in Afro-Colombian communities) while considering its social, cultural, and power-related dimensions to generate changes and improvements in teaching and learning. Unlike positivist or purely interpretative approaches, the socio-critical paradigm maintains that all educational research must be reflective and transformative in nature: “the goal of education is to transform individuals and, consequently, transform realities and contexts.”

Hence, the role of the researcher in this model is not neutral but rather that of a change agent committed to the emancipation of educational actors, with the aim of improving the conditions of the object of study. In this theoretical research, such commitment refers to the processes of selection and critical analysis of the literature, guided by the question of how to make the teaching of trigonometry more relevant and equitable for an educational

population that has historically been treated as a “marginal” student group. In alignment with the nature of socio-critical research, Participatory Action Research (PAR) is adopted as the guiding methodological approach.

It is important to clarify that, being a theoretical proposal based on bibliographic analysis, a full PAR cycle with fieldwork was not conducted. Nevertheless, the principles of PAR guide the construction of this article. Firstly, the identification of the research problem and objectives was based on the felt needs within Afro-Colombian contexts, as reported in the educational literature and ethno-educational policy documents. The literature review was then conducted in a participatory manner, incorporating contributions from various actors: previous academic studies, reflections of Afro-Colombian educators (if present in the literature), guidelines from the Ministry of Education, and theoretical voices from critical pedagogy.

The methodology involved an in-depth evaluation of these sources through key categories (problem-solving strategies, Afro-Colombian cultural context, learning outcomes in trigonometry, tensions, enablers, etc.) from which relevant findings were extracted. This process approximates the diagnostic and action-formulation phase of a PAR model. In the case of designing an applied project, the next steps would include the implementation of the proposed strategies in the field (action) and their subsequent evaluation in collaboration with the community (observation and reflection); although this is beyond the scope of the present article, the conclusions section outlines possible directions for future work.

The methodological approach of this work is that of a documentary and theoretical-conceptual qualitative study that critically engages with literature to propose lines of action. Interpretation and triangulation of secondary sources (research articles, institutional reports, pedagogical theories) are used to support arguments regarding the expected impact of contextualized problem-solving tasks on trigonometry learning. By situating the inquiry within a PAR framework, the authors adopt an active stance, aiming not merely to describe “what is,” but to establish the foundations for “what could be” a renewed educational experience in Afro-Colombian communities, offering a call for collaborative efforts and the empowerment of actors in any future intervention inspired by this study.

4 Results

From critical reflections on the literature, a series of theoretical findings can be drawn that illuminate the relationship between contextualized problem-solving and the teaching of trigonometry in schools, particularly within the context of Afro-Colombian education. Broadly speaking, the authors argue that approaching trigonometry through real-life problems significantly enhances students’ understanding of fundamental concepts. This is supported by both formal studies and descriptive classroom reports.

When trigonometric concepts (such as sine, cosine, and tangent ratios; angular relationships; the Pythagorean Theorem; and the Law of Sines/Cosines) are presented through situations familiar to students, they cease to be abstract formulas and become tools for solving meaningful problems. For example, when students face

a genuine problem, like needing to measure the width of a river without crossing it, they learn to relate a known height to an unknown horizontal distance using the tangent ratio. This imparts real-world meaning to the concept, rather than treating it as a purely theoretical construct.

Thus, problem-solving serves as a critical link between empirical and formal knowledge: learners must start with a concrete situation, construct a representation (graphical or algebraic), and arrive at a general mathematical concept. Other sources also highlight additional benefits of this process, such as the development of critical thinking and modeling skills. A student unaccustomed to solving everyday problems using trigonometry also learns to abstract and generalize, applying their knowledge in different contexts. Specifically in Afro-Colombian secondary school communities, the literature suggests that a didactic approach based on contextualized problems can have a positive, differentiated impact due to the cultural and social characteristics of these communities.

On one hand, incorporating references to the Afro-Colombian context (its geography, economic practices, and cultural heritage) into problems makes the curriculum more relevant: students see their reality reflected in what they learn. This may result in greater engagement and improved academic self-esteem. For instance, in a Pacific coastal school, trigonometry problems might involve calculating distances in artisanal fishing or determining the height of palm trees and mangroves in the surrounding area. In such cases, Afro-descendant students not only learn trigonometry but also value their traditions and context by recognizing their ability to analyze their world mathematically.

This approach aligns with the principles of ethnomathematics and the Afro-Colombian Studies curriculum, both of which aim to make Afro-descendant knowledge visible and legitimate in schools. Additionally, the associated participatory methodology (where problems are discussed collectively in class, teams are formed to solve them, and reflection is encouraged) supports the social construction of knowledge. Students learn from each other and develop communication skills by debating solutions—crucial for a deeper understanding of trigonometry, which often involves using different skills (geometric, algebraic, graphical) to solve the same problem.

Finally, from a socio-critical perspective, students’ work on contextualized problems serves to apply mathematical thinking to local challenges, empowering them to contribute to change in their communities using scientific tools. A student who understands how to measure land, calculate slopes, or predict tides or agricultural cycles using trigonometry is better equipped to participate in community projects and make informed decisions in daily life. However, the theoretical findings also highlight tensions and challenges in promoting this approach in Afro-Colombian communities, as well as unique opportunities emerging from these contexts. These aspects are summarized below.

4.1 Identified tensions

The first tension stems from the mismatch between the official curriculum and local realities. While national standards

call for contextualization, textbooks and curricula often present trigonometry through universal or culturally neutral examples, which may overlook specific cultures. This creates challenges when trying to incorporate Afro-Colombian contexts into lessons, raising questions about how to balance cultural relevance with official academic content, and how to reconcile standardized testing with contextualization. Another key tension is epistemic-cultural: school mathematics has historically been framed as Eurocentric and “superior” to ancestral Afro-descendant knowledge, which has often been devalued. Integrating cultural practices that involve trigonometric knowledge may face resistance from those who view alternative content as lacking rigor or not fitting within formal mathematics. Overcoming academic biases and fostering a dialogue between knowledge systems in the classroom is necessary. In terms of classroom dynamics, another tension arises when students are expected to shift from passive recipients of formulas to active problem-solvers. This role shift may provoke insecurity or resistance, especially in students used to traditional instruction. Transitioning from a mindset of simply applying procedures to one of exploration and critique presents its own set of challenges.

4.2 Implementation challenges

One of the main challenges is teacher training. Many mathematics teachers lack preparation in ethnoeducation or contextualized problem-solving, and the absence of didactic resources reflects this gap. Teachers must be trained not only in the cultural content (history and knowledge of Afro-Colombian communities) but also in participatory and inquiry-based methodologies to co-design contextualized activities. Another challenge is the availability of resources. Implementing real-world measurement projects, field trips, or manipulative materials for trigonometry requires instruments (measuring tapes, transits, levels, simulation software) that are often unavailable in rural or under-resourced schools. The digital divide is also a factor, as rural students may lack access to mobile applications that support trigonometric problem-solving. Additionally, the time required to teach through real-life problems is often greater than that needed for routine exercises. The demands of covering the official syllabus may prevent teachers from dedicating sufficient time to long-term contextual projects. From a social perspective, combating low expectations and stereotypes is a pressing challenge. In many Latin American schools, ideologies persist that “naturalize and legitimize failure” among Afro and Indigenous students in mathematics. To break this cycle, the entire educational community must believe in Afro-Colombian students’ potential and provide appropriate support; otherwise, even the best strategies may fail if students are made to feel that nothing is expected of them or worse, if they internalize these beliefs.

4.3 Specific opportunities

Despite the tensions and challenges, Afro-Colombian communities offer rich opportunities to enhance trigonometry

education. One opportunity lies in the abundance of meaningful everyday contexts that can be transformed into effective or engaging mathematical problems. For example, many Afro-Colombian communities on the Pacific coast rely on fishing and artisanal navigation. These activities allow for problems involving sea distance measurement using angles of elevation, estimating coastal distances based on apparent land height, or calculating water depth through imaginary triangles. In mountainous Afro-descendant areas (such as parts of Chocó), student projects could involve measuring slopes of rural paths or the height of timber trees. Afro-Colombian visual and artistic culture also provides opportunities: geometric patterns in braided hairstyles, textiles, musical instruments (drums, marimbas), and the layout of traditional dwellings in Palenque’s can be mathematically analyzed. Though many of these examples fall under plane or fractal geometry, problems involving angles in craft designs or musical resonances as sinusoidal functions can also incorporate trigonometry.

4.4 Using this cultural heritage supports contextualized learning while validating identity

Mathematics is embedded in the community’s own practices and knowledge. Moreover, communities are often eager to engage with education that affirms their heritage, opening the door to stronger partnerships between schools and communities. A classroom project guided by PAR could invite local leaders master craftsmen, experienced fishers, or elders with maritime stories to co-create problems with teachers, bringing realism and relevance. Problems co-produced with communities have a positive effect on curricular integration and foster a sense of ownership: trigonometry becomes “what we investigated in our community” rather than just “what comes from the textbook.” From an educational policy perspective, such initiatives can be supported by existing programs in ethnoeducation and quality education with a differential approach. Curricular guidelines such as those for Afro-Colombian Studies and existing ethnomathematics research provide a strong institutional and theoretical foundation for curricular innovation. With support from ministries or respected educational institutions, successful experiences in one school could be systematized and replicated regionally or nationally.

The theoretical findings begin to outline a scenario in which contextualized problem-solving fosters meaningful trigonometric learning by anchoring concepts in students’ realities, thereby strengthening cultural identity and critical thinking in Afro-Colombian communities. However, for this promising scenario to materialize, it is necessary to address the identified tensions and challenges through teacher training, resource provision, curricular flexibility, and institutional commitment to educational inclusion. These results thus serve as a foundation for the design of participatory pedagogies, which will be explored in the following conclusion section, where the transformation of these theoretical ideas into classroom and community actions is envisioned.

5 Conclusions

This sociocritical theoretical review ultimately reveals a hopeful future for the teaching of trigonometry through real-life problem-solving in Afro-Colombian contexts. First, it is concluded that teaching trigonometry through authentic problems is not only desirable but essential if the goal is to foster meaningful learning among students from culturally diverse communities. The theoretical evidence suggests that shaping a curriculum around real-world problems for students from culturally distinct backgrounds supports stronger motivation, deeper engagement, and more thorough conceptual understanding, effectively connecting school content with students' realities and breaking away from the alienation often produced by homogenized curricula.

From a cognitive perspective, teaching trigonometry as a tool for addressing real-world situations—rather than as a set of formulas to be memorized—promotes proper knowledge construction. Students build richer, more transferable mental models that allow them to apply their learning in varied contexts. From an affective and social viewpoint, this approach can transform the relationship Afro-Colombian students have with mathematics, building self-confidence and challenging longstanding narratives of inadequacy imposed by previous generations.

Secondly, incorporating the socio-critical paradigm and Participatory Action Research (PAR) into educational reflection provides a robust framework for addressing inequalities and promoting change. Viewing teachers as researchers and students as active agents in the learning process establishes a foundation for sustainable and contextualized innovation. A significant outcome of this study is the integration of key concepts—problem-solving, critical pedagogy, ethnoeducation, and PAR—into a coherent proposal. This theoretical convergence suggests that educational intervention should not merely incorporate everyday problems in isolation but should do so through a participatory process involving the school community and with the explicit goal of empowering that community.

One possible future action would be to implement a PAR project in an Afro-Colombian school by forming a community of practice that includes mathematics teachers, students, parents, and local knowledge holders. Together, they could collaborate on redesigning the trigonometry module: identifying locally rooted problems, developing contextualized teaching materials (such as a collection of community-based problems), applying this new approach in the classroom, and jointly evaluating student performance and attitudes. Such an intervention would also empirically test the hypotheses of this article, providing concrete data and experiences to enrich the theoretical framework.

In terms of educational implications, this work invites teacher educators, curriculum designers, and educational authorities to seriously consider the cultural adaptability of the mathematics curriculum. Twelfth-grade trigonometry content could become a bridge between local knowledge and global competencies when addressed through pedagogical creativity and cultural sensitivity. Training future teachers in strategies for contextualized problem-solving and cultivating their critical research attitudes is crucial to scaling up this approach.

Institutions must also allocate the time and space needed for teachers to innovate through an ethnomathematical lens. This could be achieved through professional learning communities or interdisciplinary projects that address community issues from various angles, including mathematics. The findings of this discussion also highlight the need for the creation of contextualized didactic materials—guides, problem banks, and technological resources incorporating Afro-mathematical and ethnically diverse Colombian contexts—designed and validated by experts in both mathematics content and cultural relevance.

Lastly, several future research lines emerge from this theoretical proposal. One would involve documenting Afro-Colombian ethnomathematical practices related to trigonometry: are there traditional practices of orientation, construction, measurement, or games in these communities that relate to trigonometry? Exploring such questions would require interdisciplinary fieldwork (ethnographic and didactic) to inform curriculum design. Another research path could investigate the long-term impact of contextualized interventions: beyond enhancing understanding, do these interventions influence students' academic choices or foster a stronger sense of school belonging?

It would also be valuable to compare different active methodologies (e.g., problem-based learning vs. community-based project learning) to determine which yields better trigonometry learning outcomes in vulnerable contexts. In conclusion, this work establishes a theoretical foundation that highlights the importance of contextualizing and democratizing trigonometry instruction in Afro-Colombian communities. We hope these reflections inspire the implementation of innovative pedagogical projects and empirical research that realize the transformative potential outlined here, in pursuit of a mathematics education that is more equitable, relevant, and emancipatory for all learners.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships

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